EI- TECHNOLOGY -
THE KEY FOR HIGH PERFORMANCE PROPULSION DESIGN

Beat Vogelsanger and Kurt Ryf

NITROCHEMIE WIMMIS AG, CH-3752 Wimmis, Switzerland
Tel: ext - 33 228 13 00 Fax: ext - 33 228 13 30

ABSTRACT

Recently, a new generation of propellants was successfully introduced. The so called "extruded impregnated" EI-propellants overcome several drawbacks connected with conventional propulsion systems and show a significant performance gain under system-compatible conditions in small and medium calibre applications as well as in mortars. EI-propellants are produced from extruded single base propellant grains by impregnation with a blasting oil, followed by deterring with a polymer.

In the medium calibre application range, performance gains of 7 - 12% were attained with the EI-propellant if compared to conventional alternatives. This improvement in interior ballistic performance is achieved by a combination of enhanced bulk density, slightly increased energy content, very progressive burning behaviour and a strongly reduced temperature sensitivity.

A well balanced combination of two different wear reducing agents was found to successfully counteract the adverse effect of the slight increase in flame temperature. The relatively low erosivity of the EI-propellant was confirmed in both erosion bomb tests and in trials with the weapon.

The employment of a well stabilised base grain, proven additives, and a diffusion-stable surface coating kept both chemical and physico-mechanical ageing to a very low level - excellent safe life and ballistic shelf life values are therefore attainable with EI-propellants.

1. Introduction

During the last few decades, different approaches have been made in order to improve the interior ballistic performance of propellants for medium calibre ammunition. All these "new" developments, such as deterred single and double base propellants, ball powders, consolidated charges and nitramine propellants had serious drawbacks. In the case of single base propellants and ball powders, the gain in performance was limited by the restricted energy content or by the grain geometry. In other propellant types, shelf life was reduced by diffusion of deterrents and blasting oils, or excessive gun barrel wear appeared.

Nitrochemie Wimmis AG has recently successfully introduced a new generation of propellants overcoming the drawbacks mentioned above and showing a significant performance gain under system-compatible conditions in:

- ***small calibres*** (5.56 - 15 mm),
- ***medium calibres*** (20 - 50 mm; sub-calibre / finstabilised ammunition), and
- ***mortars***.

The so called "extruded impregnated" EI-propellant is produced from extruded one-, seven- or nineteen-perforated single base propellant grains by impregnation with a blasting oil, followed by deterring with a polymer. In such EI-propellants, the blasting oil forms an outer layer several hundred micrometers thick. A diagram showing the concentration profiles of blasting oil and deterrent as well as the distribution of energy content within a typical EI-propellant grain is given in Figure 1.

The most important features of EI-propellants for medium calibre application, namely

- ***improved interior ballistic performance***,
- ***increased barrel life***,
- ***excellent safe life*** and ***good compatibility to system environment***, and
- ***excellent ballistic shelf life***

are discussed in some detail in the following chapters. Other advantages include the competitive pricing as well as the high parameter flexibility of the EI-process which allows efficient and quick developments to satisfy the specific demands of our customers.

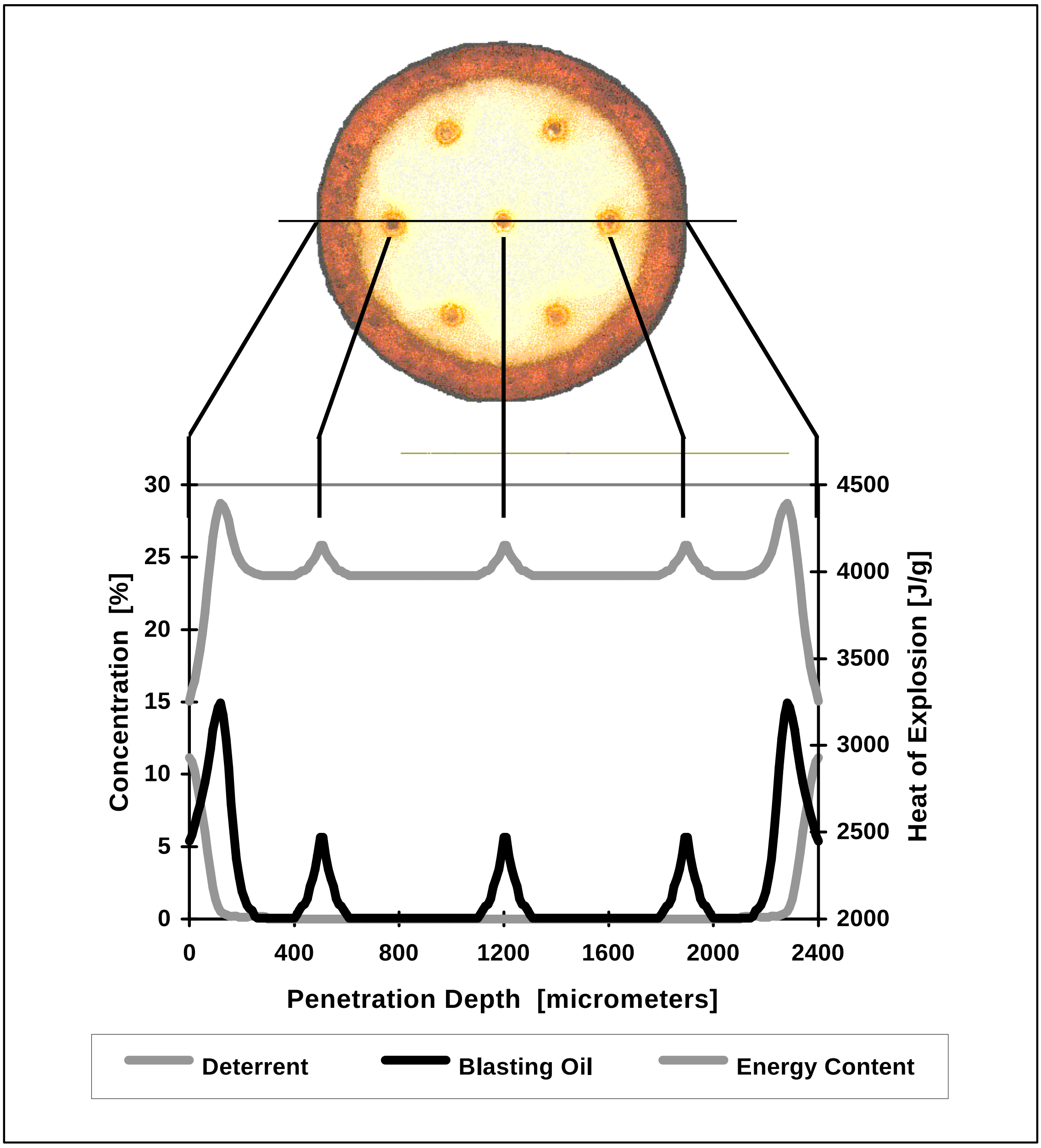

Figure 1: Blasting oil and deterrent concentration profiles as well as corresponding distribution of energy content in EI-propellant. The concentration profiles were determined by Fourier transform infrared (FTIR) microspectroscopy; the energy content was calculated using the ICT code.

2. Interior Ballistic Performance

During the last years, EI-propellants have proven their superiority over competitors' products in different medium calibre ammunition systems (in already qualified applications as well as in new developments; calibres 25, 27, 30, and 35 mm). In general, performance gains of 7 - 12% were attained compared to conventional alternatives. This improvement in interior ballistic performance is achieved by:

- ***Enhanced bulk density****:* The high bulk density (up to 1100 g/dm^3) allows an increase in the charge weight in the cartridge without consolidation. Enhancement of charge potential directly equals performance gain.

- ***Slightly increased energy content****:* Due to the added blasting oils, the energy content is increased by 200 - 300 J/g compared to single base propellants. This additional chemical energy contributes to the performance gain.

- ***Very progressive burning behaviour****:* The burning characteristic of surface coated propellants is dominated by the distributions of coating agents and energy content (see Figure 1). In case of EI-propellant, the deterred outer surface can be expected to burn much more slowly than the undeterred regions of the grain. This is confirmed by the results of intercepted bomb tests showing that combustion will start mainly from the perforations, whereas the energy-rich, blasting oil containing outer layer burns later in the interior ballistic cycle - exactly at the stage where its energy is needed most. This very progressive burning behaviour further adds to the performance gain.

- ***Reduced temperature sensitivity****:* Thanks to the high parameter flexibility of the EI-process, it is possible to alter the product's properties regarding temperature coefficients of muzzle velocity (v_0) and peak pressure (p_{max}) within certain limits. Therefore, the strong temperature sensitivity known from conventional products can be reduced considerably in EI-propellants. This allows the performance potential given by the system limits of the weapon system to be fully exploited - the maximum performance is obtainable at service temperature.

The excellent interior ballistic behaviour of EI-propellants is demonstrated in Figure 2. An EI- and a single base propellant, both optimised for the specific application, were tested in the APFSDS-T round for the 30 x 173 mm Bushmaster II gun. Thanks to its higher performance level and reduced temperature sensitivity, the EI-propellant enables a gain in kinetic Energy E_0 of 18% at -50°C, and of 12% at +21°C, to be made.

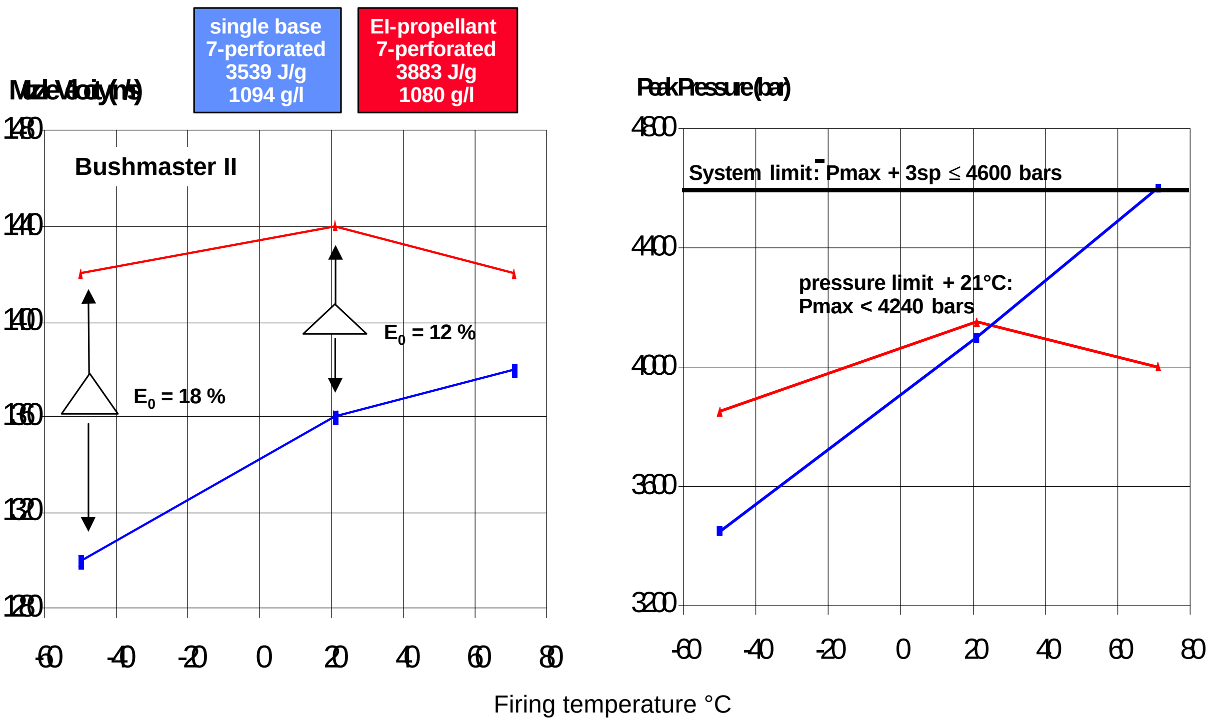

Figure 2: Interior ballistic results obtained with the APFSDS-T round for the 30x173mm Bushmaster II gun. The low temperature sensitivity as well as the significant increase in performance obtainable with the EI-propellant are clearly visible.

3. <u>Barrel Erosion</u>

From practical experience it is known that each increase in the propellant's energy (or flame temperature) will reduce the barrel life considerably. However, with high performance ammunition (especially kinetic energy munitions) one cannot avoid using a charge with a sufficiently high energy content.

In the case of EI-propellant for medium calibre application, the extent of barrel wear is kept to an acceptable level by:

- ***Relatively low flame temperature****:* For an EI-propellant designed for 25 mm ammunition, flame temperatures of around 3000 K are calculated (using the ICT code). This value lies somewhat higher than the 2800 K of a single base propellant for the same application, but is far below the 3500 K calculated for a nitramine propellant already in service.

- ***Optimised barrel protection measures (additives)****:* In order to achieve the maximum possible barrel protection over the entire interior ballistic cycle, two different additives are employed ("two-phase design"). One of the additives is located at the surface of the propellant grains to ensure sufficient protection from the beginning of the cycle (effect in transition zone - free flight zone). The second additive, being incorporated in the base grain matrix, is released continuously up to the end of combustion (effect on barrel up to muzzle proximity). The introduction of these additives must be balanced in such a way that no contamination or fouling occurs. It must be noted that the two additives used in small quantities are not exotic ones but known and proven "agents".

The barrel protection concept described above has demonstrated its effectiveness in both erosion bomb and weapon firing tests.

The results of the ***erosion bomb*** tests are given in Figure 3 (diagram of the weight losses of the nozzle as a function of the heat of explosion). From this diagram it is evident that the erosivity of the EI-propellant lies in the same range as for different highly surface-treated and thus so-called "cool" burning single-base charge variants, whereas the "hot" burning nitramine propellant is in the upper investigation range.

During NATO-Homologation at the NATO test centre in the Netherlands, EI-Propellant in a 25 mm APFSDS application ***met the barrel life requirements of STANAG 4173 in both Bushmaster and KBA gun***.

Extensive trials in the 27 mm Mauser gun revealed a ***barrel life*** of substantially more than 3000 rounds for APFSDS ammunition in conjunction with EI-propellant.

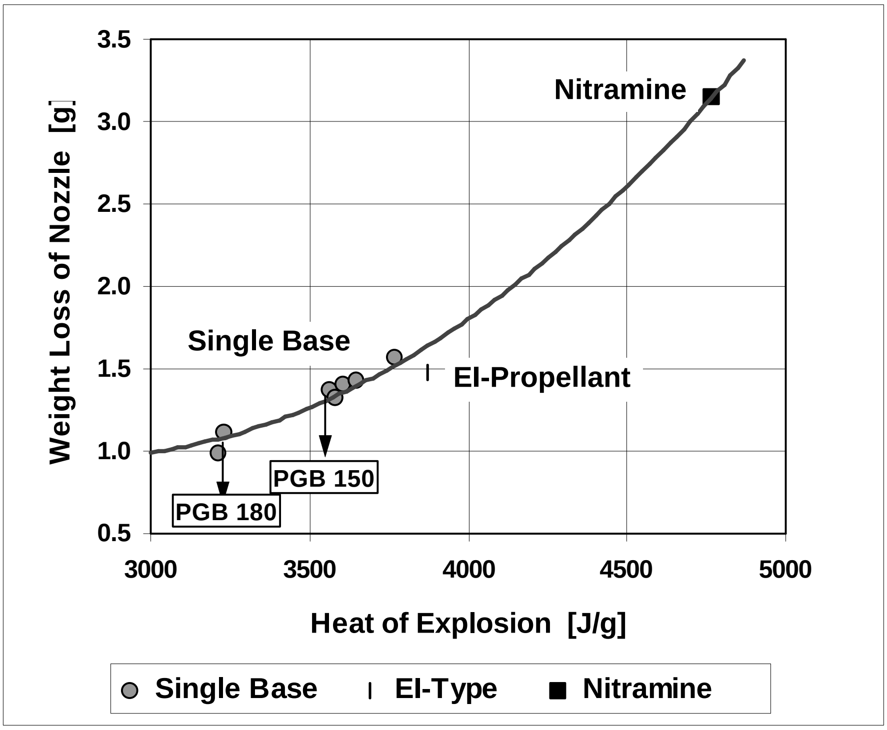

Figure 3: Results of erosion bomb test for different 25 mm calibre propellants (single base, EI-, and triple base / nitramine). As can be seen from the diagram of the weight losses of the nozzle as a function of the heat of explosion, erosivity increases superproportionally to increasing thermal value. The erosivity found for the EI-propellant did not significantly differ from the values obtained for different deterred single-base propellants such as PGB 150. The two propellants PGB 180 and PGB 150 both meet the barrel life values required in STANAG 4173 when the relevant load rates are applied.

4. Chemical Stability / Safe Life

For the production of EI-propellants, a carefully manufactured and well stabilised base grain is used, and only known compatible and proven ingredients or additives are applied. Thus, chemical ageing under normal storage conditions is kept to an almost negligible level, and an excellent chemical shelf life (safe life) will result. This was proven in different experiments:

***Conventional stability tests**:* EI-propellants have been subjected to numerous conventional stability tests during development, qualification and production, e.g. to the 90°C weight loss test, 105°C Dutch test, and 115°C Bergmann-Junk test. All test requirements have been fulfilled.

Heat flow calorimetry / NO_x-chemiluminescence: The extremely sensitive heat flow calorimeter and NO_x chemiluminescence detectors, monitoring the actual evolution of heat and nitrogen oxides even at moderate storage conditions (30 - 80°C), confirmed the very low ageing rate of EI-propellants.

Chemical shelf life determination: The chemical shelf life (safe life) of different propellants was determined, whereby the propellant samples were subjected to accelerated ageing for up to 108 weeks at temperatures of 40°C, 50°C, 60°C and 70°C. The remaining stabiliser contents were assayed quantitatively for the unaged propellant as well as for all artificially aged samples by high performance liquid chromatography (HPLC). From the results, the time period for 50% stabiliser consumption was calculated and interpolated to designated storage conditions using the Berthelot equation. This approach is known to be very conservative. The results of these investigations are shown in Figure 4.

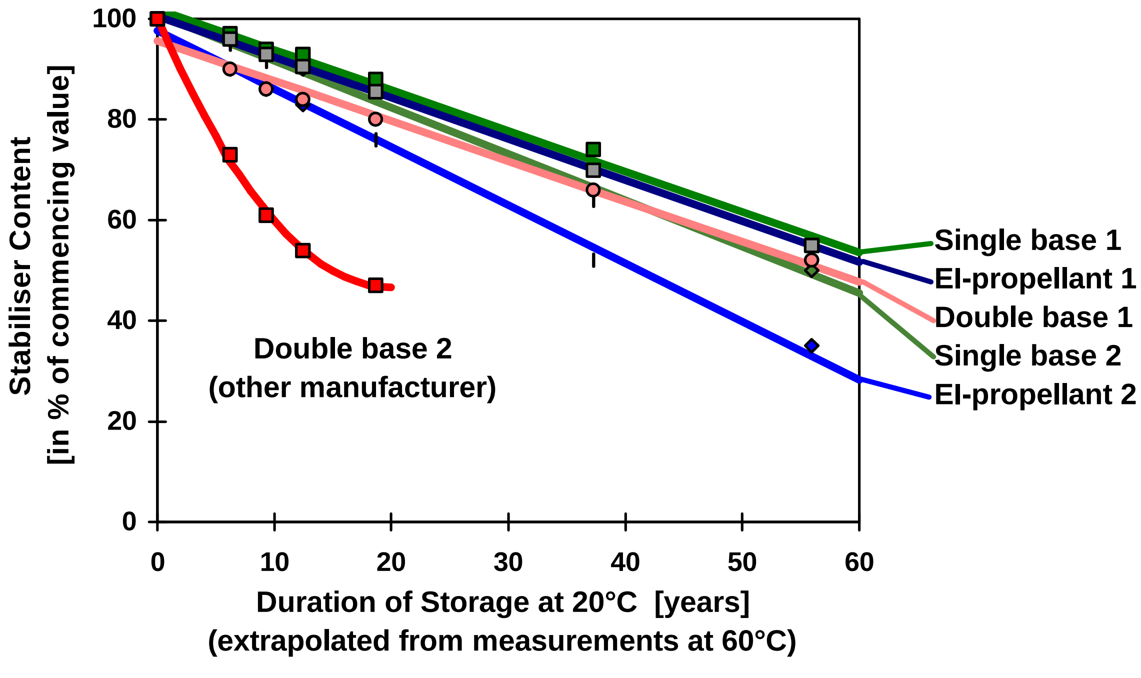

Figure 4: Assessment of chemical shelf life (safe life) for different propellant types. All propellants except "double base 2" have been produced by Nitrochemie Wimmis AG. The safe life values extrapolated from 60°C to 20°C exceed 40 years for all propellants, except for "double base 2" which only manages to reach 15 years (very conservative estimations). The extrapolation was made using the Berthelot approach with an ageing factor of 3.0. The Berthelot law implies that each temperature change of 10°C will increase the rate of

propellant ageing by this factor. From numerous investigations it was found that the ageing factor generally extends between 3 and 4.

For ***EI-propellants***, the ***safe storage life*** was determined to be in the range of ***20 - 40 years at 30°C***, and of ***50 - 100 years at 20°C***, respectively.

This excellent behaviour has been confirmed by the recent analysis of two EI-propellants of the same recipe, produced in 1985 and 1995. Despite the older sample having been stored for 10 years under ambient conditions, it was still found to be chemically identical to the new propellant, as can be seen from Table 1. In particular, the concentrations of primary stabiliser as well as the contents of stabiliser derivatives were found to be equal within the accuracy of the method.

Type	**Substance**	**Sample "1985"**	**Sample "1995"**
Primary stabiliser	Acardite II	1.01 %	0.99 %
	2-Nitro-diphenylamine	0.09 %	0.12 %
Stabiliser derivatives	N-Nitroso-diphenylamine	0.01 %	0.02 %
	4-Nitro-diphenylamine	< 0.01 %	< 0.01%
90°C Weight loss test		1.36 %	1.26 %

Table 1: Results of HPLC-analysis of two EI-propellants of the same recipe, produced in 1985 and 1995. Both samples were analysed simultaneously in spring 1996. The results of the 90°C weight loss tests are given as well.

5. Ballistic Shelf Life

In order to guarantee sufficient ballistic shelf life, the phenomena that might contribute to the changes in the interior ballistic behaviour have to be kept to an acceptable level. For surface-coated propellants, the main factors are molecular weight reduction of the nitrocellulose and the diffusion of surface coating agents into the propellant grain. Both processes have been investigated in some detail:

- ***Nitrocellulose degradation***: From experience we know that changes in the ballistic characteristics may occur once the molecular weight of the nitrocellulose has been reduced by more than 45%. Shelf life investigations of EI-propellants, performed by ageing the samples as described in section 4 and monitoring the nitrocellulose degradation using size exclusion chromatography (SEC), predicted a molecular weight reduction of only 40% after approximately 60 years at 20°C. Thus, nitrocellulose degradation does not adversely affect the ballistic properties during the designated shelf life of the round. The low extent of nitrocellulose depletion corresponds to the other chemical ageing processes (the "chemical" ageing processes, such as stabiliser consumption, nitrocellulose degradation, heat and nitrogen oxide evolution are strongly connected with each other - in a well stabilised propellant, all those processes are of low magnitude).

- ***Diffusion of deterrents and blasting oils**:* The diffusion of numerous deterrents and blasting oils into different propellant matrices during accelerated ageing was investigated using Fourier transform infrared (FTIR) microspectroscopy. The diffusion coefficient values determined by fitting a Fickian diffusion model to the observed concentration profiles correlated to the changes in the interior ballistic behaviour. It was found that the diffusion effects in single base propellants are too small to significantly alter the ballistic performance. In double base propellants, however, the diffusion of deterrents is much faster and will most likely limit the ballistic shelf life. In EI-propellants, the diffusion of surface coating agents can be minimised by carefully balancing type and concentration of both polymeric deterrent and blasting oil. In such EI-propellants, diffusion effects are only marginally higher than in single base propellants, and excellent ballistic shelf life values are achieved. Figure 5 compares the diffusion of the polymeric deterrent in EI-propellant to the diffusion of dibutylphthalate (DBP) in a double base propellant.

Assessment of ballistic stability**:* Ballistic shelf life is determined using a test plan similar to the one described in section 4. The propellant is aged artificially for up to 36 weeks at temperatures of 40°C, 50°C, and 60°C before being tested in the weapon at different firing temperatures. The results are extrapolated to standard storage conditions using an ageing factor of 3.0 which is known to be a conservative estimation. This test has been performed for ***different weapon / ammunition systems in conjunction with EI-propellant, revealing ***excellent ballistic shelf life*** values in all cases. Over the entire range of firing temperatures (usually -54°C to +71°C), only marginal changes in peak pressure and muzzle velocity were introduced by artificial ageing periods equivalent to 20 years storage at 20°C. In particular, no dangerous rises in peak pressure (> 150 bar) appeared, and the low temperature sensitivity of the EI-propellant was maintained, thereby proving the effectiveness of the measures to reduce nitrocellulose degradation as well as blasting oil and deterrent diffusion.

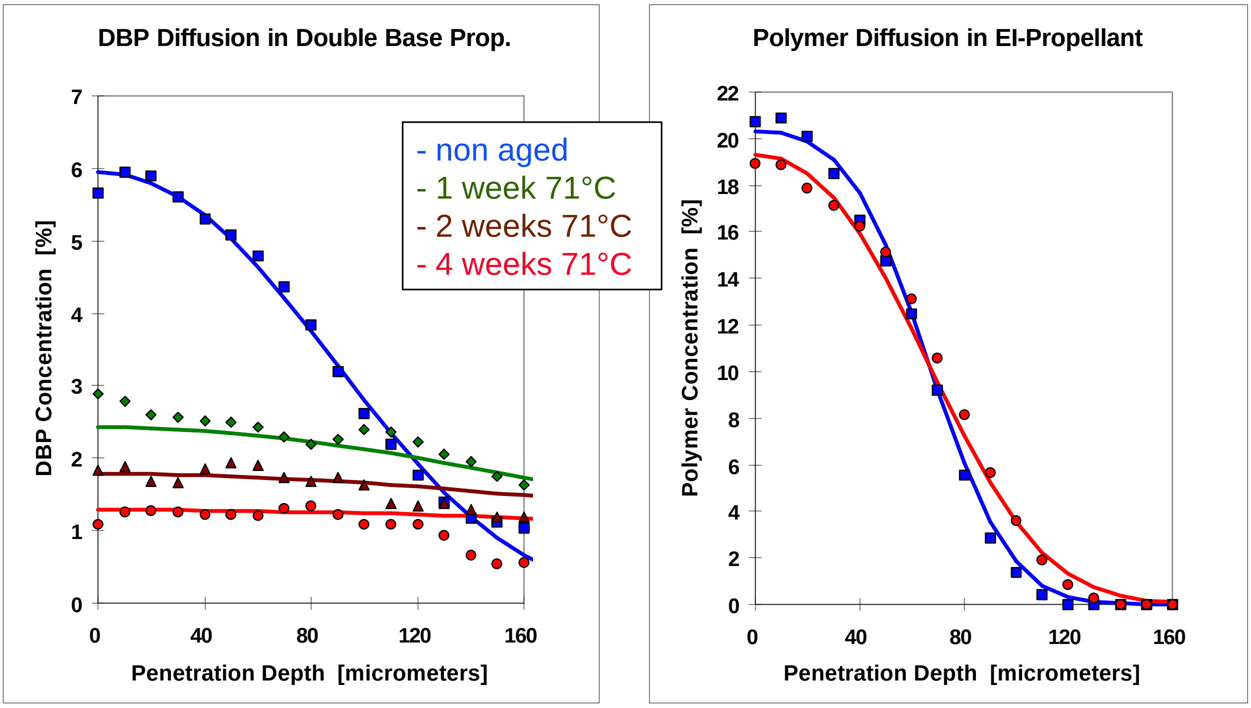

Figure 5: Investigation of the diffusion of deterrents; concentration profiles of dibutyl-phthalate (DBP) in double base propellant and polymer in EI-propellant, determined by FTIR-microspectroscopy. Measured concentration values (dots) and recalculated concentration profiles (lines) for t_0 (unaged propellant), t_1 (propellant stored at 71°C for 1 week), t_2 (2 weeks at 71°C) and t_4 (4 weeks at 71°C). The deterrent diffusion is very small in the EI-propellant and therefore will not influence the ballistic shelf life (diffusion coefficient determined to be $D = 0.13 \cdot 10^{-15}$ m^2/s). In the double base propellant, however, the diffusion is increased by more than two orders of magnitude ($D = 26 \cdot 10^{-15}$ m^2/s) - such strong diffusion effects will reduce the ballistic shelf life considerably.

The results of ballistic shelf life assessments for five different propellants are depicted in Figure 6. It is evident from this diagram that the single base and all three EI-propellants exhibit shelf life values of more than 20 years, whereas for the propellant with a strongly diffusing surface coating, the ballistic shelf life is reduced to about 10 years at 20°C.

The excellent ballistic stability of EI-propellant was confirmed during different qualification and homologation procedures. In particular, environmental and climatic condition tests such as MIL STD 810 D have been fulfilled without problems. The most severe environmental test program, however, was performed at DGA in Bourges (F). The 30 mm rounds filled with EI-propellant were subjected cumulatively to a "simulation of climatic conditions" (80 days at +71°C / 20% rel. humidity to +60°C / 80% rel. humidity), 30 cycles "simulation of aircraft conditions" (totally 780 hours from -40°C to +100°C), 3 cycles of "complete firing action" (+21°C to +121°C), and a "vibration test", before being fired in the temperature range -40 to +100°C. Considering the extreme thermal and mechanical stresses involved in this test procedure, the increase in peak pressure found to be within 0 and 200 bar over the entire range of firing temperatures has to be regarded as small. The maximum pressure level obtained with the aged ammunition was still far below the system limits.

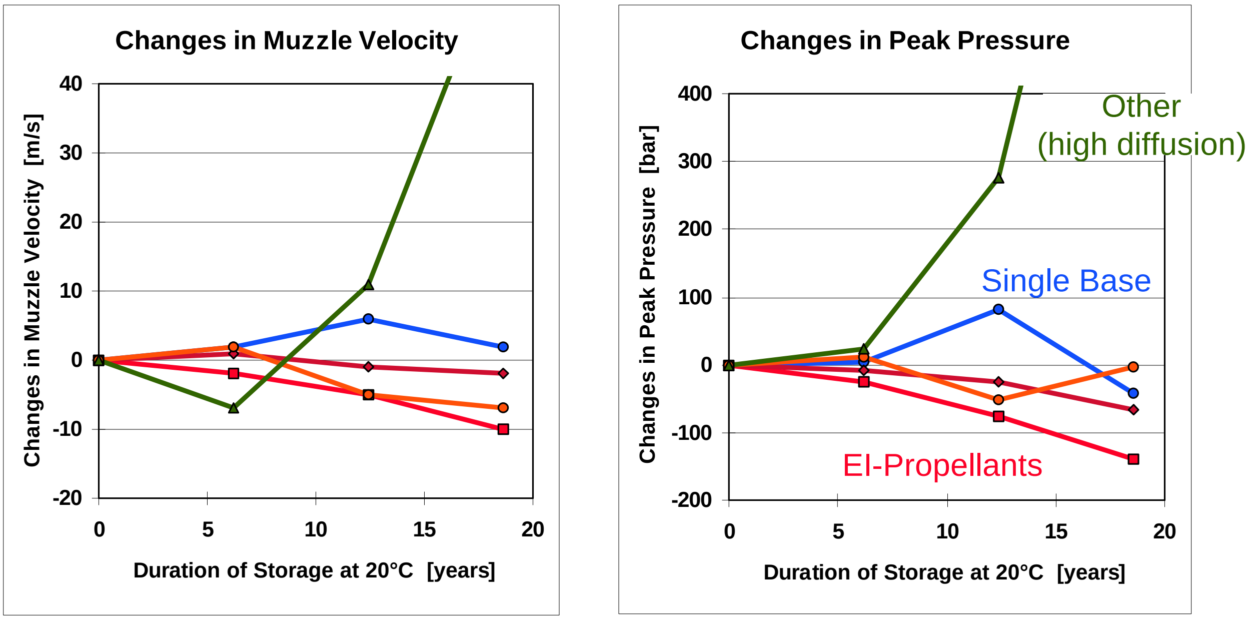

Figure 6: Assessment of ballistic shelf life for different medium calibre propellants. The propellant samples stored for 0, 4, 8 and 12 weeks at 60°C have been tested in the respective weapon systems (temperature during firing test 21°C). The extrapolation from 60 to 20°C was carried out according to the Berthelot equation with an ageing factor of 3.0. The single base as well as the three EI-propellants exhibit only marginal changes in muzzle velocity v_0 and peak pressure p_{max}; a ballistic shelf life of at least 20 years can therefore be guaranteed for all these propellants. In the sample "other composition", however, the diffusion of improperly balanced surface coating agents leads to an excessive rise in peak pressure which significantly reduces the ballistic shelf life of this propellant. The weapon / ammunition systems are: 25mm KBA APFSDS (single base), 25mm KBA APDS (EI-propellant 1), 27mmx155 APFSDS (EI-propellant 2), 30mmx190 APFSDS-T (EI-propellant 3), and 25mm KBB APDS (other composition).

6. Conclusions

EI technology has opened new perspectives in the field of high performance medium calibre ammunition. Thanks to the system-compatible behaviour of this product, a combat rate enhancement can be achieved without drawbacks or undesirable side effects. EI-propellants are equally suited for application in already introduced ammunition systems as well as in new developments.

As a result, EI technology has established itself with much success especially in the following applications:

25 mm x 137	APFSDS, APDS, FAPDS (frangible) qualified according to STANAG 4173 (NATO homologation) for use in Bushmaster (M242) and KBA-gun
27 mm x 155	APFSDS qualified according to STANAG 4170 type classified in Germany for use in TORNADO-gun
30 mm x 173	APDS, APFSDS for use in Bushmaster II and Mauser F-gun
35 mm x 228	APFSDS, FAPDS (frangible) qualified according to STANAG 4170 type classified in Germany for use in RH 503 gun
50 mm CTA	APFSD Development for the RH 503 gun

In recent years, close cooperation has been built up in these field with competent system partners, such as (in alphabetic order) Giat, Mauser, Mecar, Oerlicon Contraves, Primex, Raufoss, Royal Ordnance, Rheinmetall, among others. Such cooperations permitted investigation of system-compatible behaviour of the EI-propellant under a great variety of configurations and performance requirements. As a result, the reliability of this system component can be regarded as being fully established.

Acknowledgements

Financial support by the Gruppe Rüstung (GR), SWIT (different LFP-Projects) is gratefully acknowledged. Special thanks go to Mrs. R. Sopranetti, Mr. B. Ossola, Mr. E. Gurtner, Mr. U. von Mühlenen and Dr. S. De Boni for contributing to this work.